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The Dr. Gary B. and Pamela S. Williams Honors College

Spring 2019

Virtual Experiments and Simulations in the Science Classroom

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Honors Research Project:

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Introduction

The main goal of this paper is to analyze the use of virtual experiments and simulations within the science classroom. This analysis will be completed by first reviewing the learning theories in education. Then I will specifically analyze virtual experiments and how they are used in the science classroom. At the time of this study I had the privilege of completing my student teaching experience in a high school science classroom. This gave me the ability to have direct contact with students in order to observe their interest and engagement with simulations as well as their learning throughout the semester. I also took the opportunity to apply the strategies that will be explained within this paper. Lastly, I will discuss some of the challenges that come along with the use of virtual experiments and simulations.

Learning Theories

Before examining virtual experiments, I first need to discuss different learning theories and how they are used in education. According to Illeris (2004), "Learning Theory describes how students absorb, process, and retain knowledge during learning." (Illeris, 2004, p. 1). Prior experience, as well as cognitive, emotional, and environmental factors, all have a role in how understanding is attained.

Some learning theories state that students need to build on their previous learning in order to make connections with the new information they are taking in. According to Adams (2010), "Research on learning shows that students need a framework of the main ideas to build knowledge on (Bransford). In other words, learning is an active process where students are active sense makers. Learning is thinking and not just doing. Direct instruction does not help students build their own mental framework while pure discovery might help build a framework, but it'd take about 500 years. Successful activities should help the student identify what is important and build a mental framework for examining the phenomena. Without this framework, there are too many details to for students to follow and remember." (p. 3). With this idea in mind, I made sure to structure my lessons in order to help my students build a framework throughout their learning. When introducing new concepts, I would encourage my students to draw connections to the information that they had previously learned. This allowed them to connect new ideas to previous ideas in order to build that mental framework.

There are many different learning theories; however, there are five major learning theories that are used in classrooms today. These theories are the following: behaviorism, cognitivism, constructivism, humanism, and connectivism. Each of these play a role in describing how students learn. However, the important thing to remember is that each theory is quite different and explains learning in different ways.

Behaviorism is important in the classroom because it involves the idea of positive and negative reinforcement as effective tools of learning. It also looks at behavior modification as well as a punishment and reward system. Cognitivism is important in the classroom because it encourages the teacher to understand that a child develops cognitive pathways in understanding and a physical response to experiences. From this learning theory came different teaching strategies that were developed by Jean Piaget and these teaching strategies are used in many classrooms. Constructivism is the idea that people are responsible in creating their own understanding of the world and in order to understand new experiences, they need to use what they know based on previous experiences and make a connection. The next learning theory is humanism.

The central focus of humanism is the idea that the individual is a subject and that learning is a natural process that helps a person reach self-actualization. Important factors of humanism are scenarios and role modeling, as well as experiences, exploring and observing others.

A more recently developed learning theory is connectivism; I want to highlight this theory because I know that my classroom lessons were mostly structured around this theory. According to Siemans (2005), "Connectivism is a relatively new learning theory, developed and based upon the idea that people process information by forming connections. This theory has developed with the digital and technology age, adapting to advances in these arenas. This new theory suggests that people no longer stop learning after formal education and continue to gain knowledge from other avenues such as job skills, networking, experience and access to information with new tools in technology" (p. 1).

With the explanation of connectivism in mind, I will continue to analyze effective ways to help students learn. One of the teaching strategies that is effective in supporting student learning is the use of simulations and virtual labs. The use of simulations in the classroom came about once technology was readily available. This ties together the connectivism learning theory with the use of technology as a teaching strategy. This will be further explored after first defining what simulations and virtual labs are and how they were used within my classroom.

What Are Simulations

There are a large variety of simulations that can be discussed. A simulation is an imitation of a situation or process that can be used to provide a visual explanation. The two simulation systems that will be discussed within this study are PhET simulations and Gizmos Activities.

I used PhET simulations within my classroom in order to increases my students' understanding of the science concepts that we were discussing in class. According to Perkins (2006), "The Physics Education Technology (PhET) project creates useful simulations for teaching and learning physics and makes them freely available from the PhET website. The simulations (sims) are animated, interactive, and game-like environments in which students learn through exploration. In these sims, we emphasize the connections between real-life phenomena and the underlying science and seek to make the visual and conceptual models of expert physicists accessible to students. We use a research-based approach in our design—incorporating findings from prior research and our own testing to create sims that support student engagement with and understanding of physics concepts" (Perkins, et. al., 2006, p. 18). The most important piece stated above, is the fact that they structure the simulations to encourage student engagement. As stated in the learning theories section, it has been shown that when students are engaged in their learning, they will understand the science concepts at a higher level than those who are not engaged.

According to Wieman, et. al. (2008), "PhET sims can help: introduce a new topic, build concepts or skills, reinforce ideas, and provide final review and reflection. Sims are unique in the way they can blur the boundaries between lecture, homework, in-class activities, and laboratory, because one sim can be used in similar ways in all of these.

They also can provide a common visualization between students and teacher that can facilitate all communication and instruction" (p. 682).

The other virtual experiment system that I used was Gizmos: Explore Learning. According to their website, Gizmos Activities can be described as the following: "Gizmos are interactive math and science simulations and Gizmos use an inquiry-based approach to learning that has been validated by extensive research as a highly effective way to build conceptual understanding." I used Gizmos within my classroom because they developed my students' sense of inquiry through fun activities.

Simulations can be used in a variety of ways. They are most commonly used within the classroom in order to teach concepts that may be difficult to explain, but easier to visualize. In the paragraphs to follow, we will examine different ways that simulations and virtual experiments can be used within the classroom.

Ways to Use PhET Simulations in Teaching

Throughout my student teaching experience, I used PhET simulations and Gizmos activities in a variety of ways. The three main strategies that I used were lecture, group/individual activities, and exploratory labs.

One way that I used simulations in my lectures is by introducing a topic, then having students complete an online simulation. After the students have completed it, I would then take the opportunity to discuss with the students what they have learned. Later in this paper, there will be a more in-depth explanation of these virtual experiments and the work that was completed alongside it. I also used Gizmos as an individual or small group activity. The students would be asked to complete the Gizmos in class, and if they were unable to finish, then the rest would be homework. These in class activities were used to either introduce the topic or review the topic for an upcoming assessment. The third way that I used Gizmos activities was as an "exploratory lab". Throughout the school year we completed many hands-on labs where the students had to use their sense of inquiry and problem-solving skills in order to complete the lab. However, within physics there are many topics that are discussed that are difficult to explain using a hands-on lab. For example, roller coasters are often used when discussing physics, and it's obviously impossible to ask my students to build a real roller coaster in order to test different variables. Therefore, this is a perfect example of where using simulations to explore a concept is needed. I will explain exactly how I used this Gizmos activity later in the paper.

The above described different ways that I used simulations within my classroom, but there are obviously very many different strategies that can be used when utilizing simulations. The table below has accredited strategies for addressing the use of simulations in order to teach the science standards.

TABLE 1

Using sims to engage students in *NGSS* science and engineering practices.

***NGSS* science and engineering practice**	**Strategies for addressing this practice with simulations Have students...**
Asking Questions (science) and Defining Problems (engineering)	• List questions as they freely explore a simulation • Use simulations as a starting point to generate questions for further exploration or discussion • Pose a hypothesis they can answer with the sim
Developing and Using Models	• Generate rules (models) to explain behavior they observe in a simulation • Discuss how the simulation is a model of a scientific phenomenon • Compare data collected from the simulation model to what would be expected from other models • Use the simulation model as a tool to make or test predictions • Identify and discuss simplifications or limitations of the simulation model
Planning and Carrying Out Investigations	• Design experiments and collect data to test a hypothesis • Collect data to determine how different variables affect a phenomenon • Decide what data counts as evidence and how to collect it systematically in the simulation • Plan how to use a simulation so that they can answer guiding questions
Analyzing and Interpreting Data	• Analyze quantitative or qualitative data collected from the simulation about how different variables affect a phenomena • Write down interpretations and summaries based on observations or data collected from the simulation • Organize data collected in ways that help interpretation (e.g., graphs)
Using Mathematics and Computational Thinking	• Generate or verify mathematical models of relationships between variables, based on data collected • Create graphs of quantitative data collected from simulations
Constructing Explanations (science) and Designing Solutions (engineering)	• Use simulations to visualize underlying mechanisms (e.g., invisible or expert representations) • Summarize relationships between variables that they observed in the simulation • Explain why systems behave the way they do, based on observations from the simulation • Design solutions based on evidence from the simulation
Engaging in Argument From Evidence	• Justify conclusions using observations and data collected from simulations • Discuss the simulation and implications in the real world • Evaluate competing explanations or models, based on evidence from the simulation
Obtaining, Evaluating, and Communicating Information	• Write down summaries of what they discovered through interacting with the simulation • Discuss information they collected while exploring a simulation • Present about what they learned from simulations • Create and share an informational video using the sim and their narration to communicate science ideas • Evaluate the validity of the simulation as a source of information: compare data collected from the simulation model to other sources of information about the topic

Table 1: Using simulations to engage students in the science standards. (This table is taken directly from "Teaching with Simulations" – Price, et. al – March 2019 NSTA – *The Science Teacher*. Page 47)

Some important sections that I want to highlight are “Analyzing and Interpreting Data” and “Constructing Explanations (science)”. Within that first section, Perkins et. al. (2006), discusses different strategies that can be used, with the most important being: “analyze quantitative and qualitative data collected from the simulations about how different variables effect a phenomena”. This strategy was greatly used in my classroom because I knew this would help my students learn the concepts we were discussing in class. By analyzing the data and applying it to a phenomenon, they were encouraged to have a better understanding of what they were doing, versus just completing the activity. Through analyzing and interpreting data, students can draw conclusions and explain the information, which in turn assists them in learning the concepts. Within the section “Constructing Explanations” Perkins states: “summarize relationships between variables that they observed in the simulation.” I asked my students to do this with all the Gizmos activities that we completed in class. I knew that if they understood the relationship between the variables, then they would have a greater understanding of the information being discussed. Now I will explain how I specifically used Gizmos within my classroom lessons.

Application in My Classroom

Gizmos Activities and How They Were Used in Class:

Solubility and Temperature

This Gizmos Activity was completed as an exploratory lab for my students to gain a higher understanding of the science concepts. The students were given a packet to complete. Within the packet the students were asked to work through the activity on the computer and there was information in the packet that needed to be filled in. This included items like measurements taken and the students' predictions of what may happen, etcetera. This virtual experiment was paired with a hands-on experiment and after both were completed, the students were then asked to complete a typed lab report that contained questions from both activities.

Description from Gizmos: "Add varying amounts of a chemical to a beaker of water to create a solution, observe that the chemical dissolves in the water at first, and then measure the concentration of the solution at the saturation point. Either potassium nitrate or sodium chloride can be added to the water, and the temperature of the water can be adjusted."

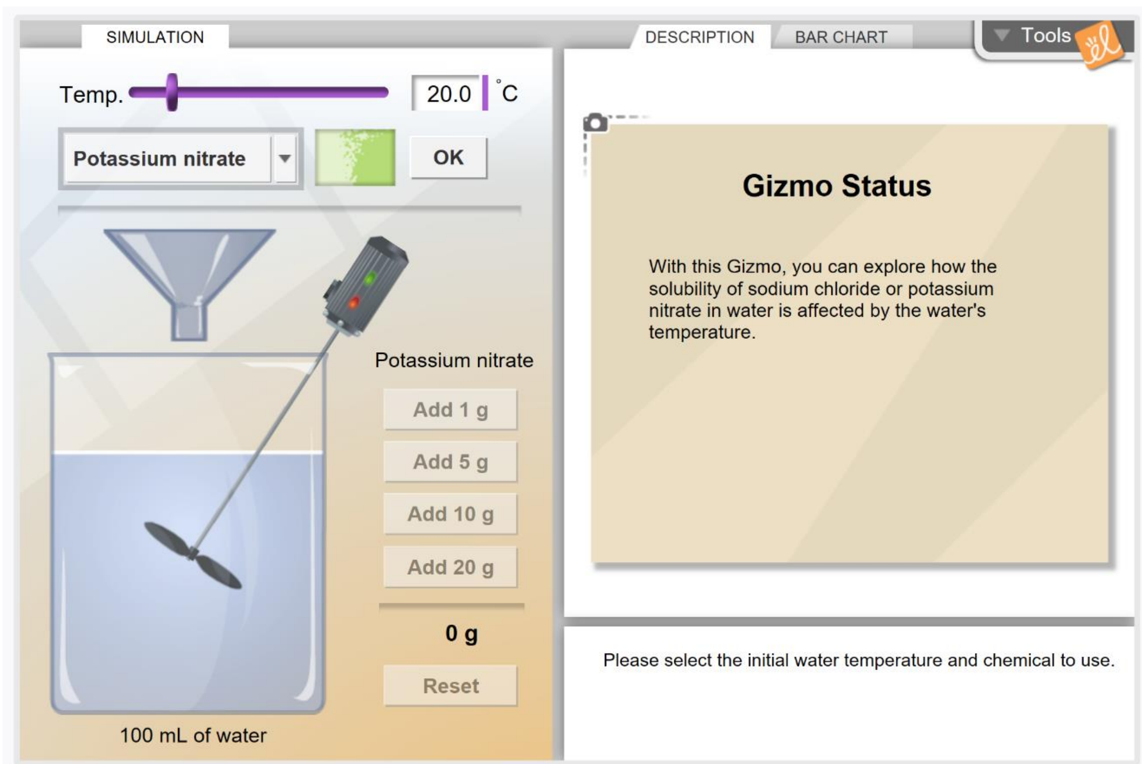


Figure 1: Screenshot of the Solubility and Temperature Gizmos activity. https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=384&ClassID=2647683

Phase Changes

This Gizmos Activity was completed as an exploratory lab for my students to gain a higher understanding of the science concepts. Very similar to the previous Gizmos, my students completed this alongside a hands-on lab. The goal was to reinforce the information that they had learned in class.

> Description from Gizmos: “Explore the relationship between molecular motion, temperature, and phase changes. Compare the molecular structure of solids, liquids, and gases. Graph temperature changes as ice is melted and water is boiled. Find the effect of altitude on phase changes. The starting temperature, ice volume, altitude, and rate of heating or cooling can be adjusted.”

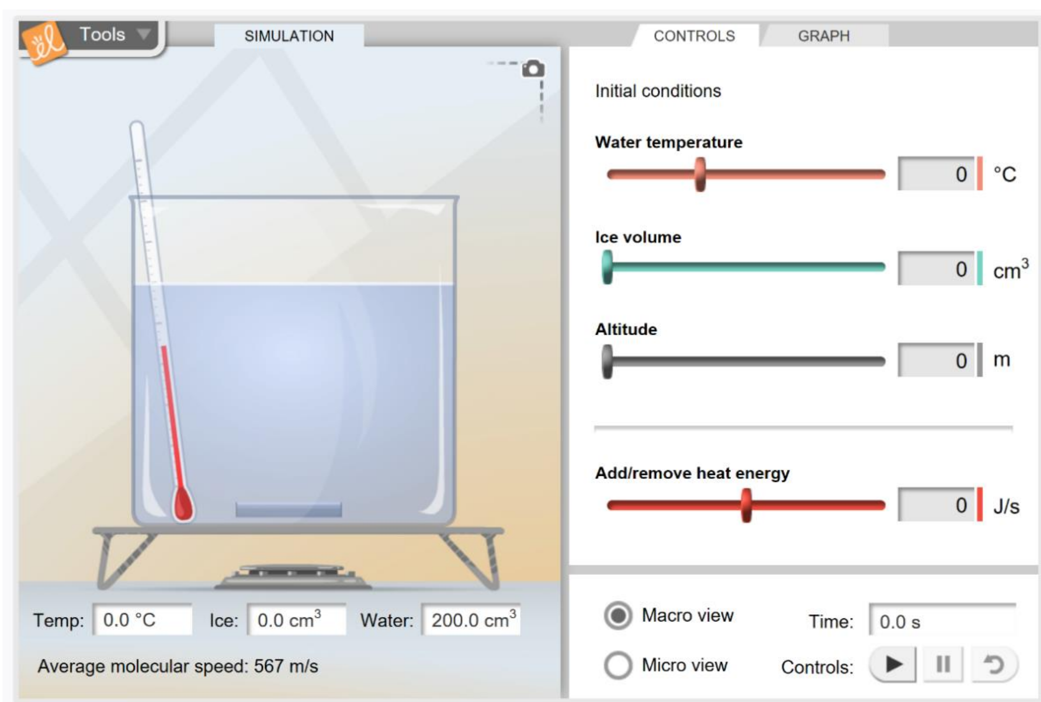


Figure 2: Screenshot of the Phase Changes Gizmos activity.

https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=557&ClassID=2647683

Ionic Bonds

This Gizmos Activity was completed as a test review in order to prepare my students for the upcoming assessment over the information. I wanted to give them the opportunity to manipulate ionic bonds and see the effects that it would have. There was not a formal lab report to be completed after this activity; however, there was a packet that they were able to work through. The packet also served as the study guide for the night in preparation for their exam.

> Description from Gizmos: "Simulate ionic bonds between a variety of metals and nonmetals. Select a metal and a nonmetal atom, and transfer electrons from one to the other. Observe the effect of gaining and losing electrons on charge and rearrange the atoms to represent the molecular structure. Additional metal and nonmetal atoms can be added to the screen, and the resulting chemical formula can be displayed."

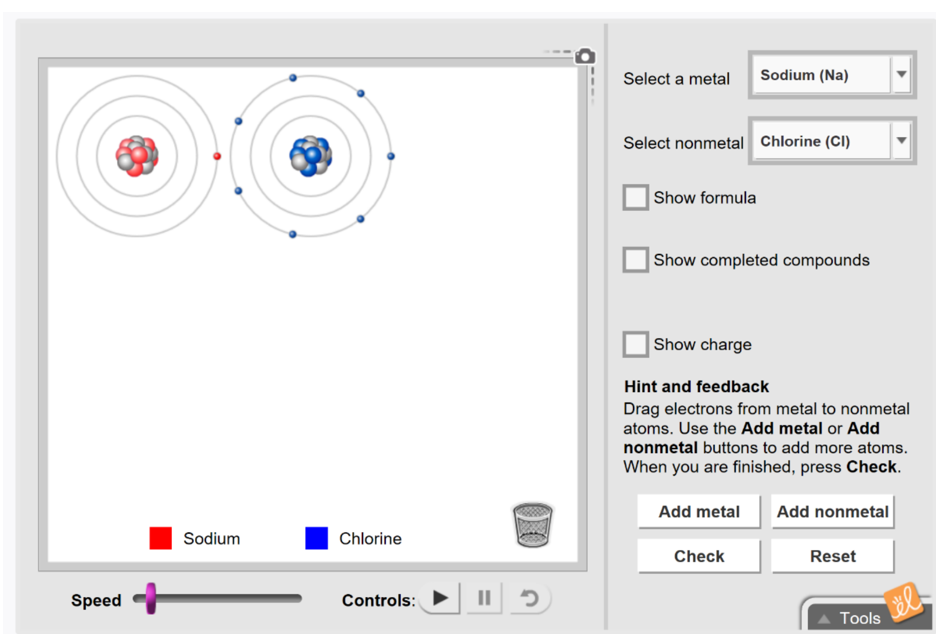


Image 3: Screenshot of the Ionic Bonds Gizmos activity.

https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=514&ClassID=2647683

Distance Time Graphs

This Gizmos Activity was completed as a small group activity prior to the lesson I was going to give over this information. The main goal for this activity was for my students to get exposed to this process before I gave them a more in-depth explanation. There was a packet to be completed along with the Gizmos activity. Once we went over the lesson in class, I had the students take out their packet and we went over the correct answers. The students were able to see what they may have gotten wrong, now that they had a better understanding of the science concepts. After this was completed, I had my students complete a worksheet for homework to verify that they understood the information.

Description from Gizmos: “Create a graph of a runner's position versus time and watch the runner complete a 40-meter dash based on the graph you made. Notice the connection between the slope of the line and the speed of the runner. What will the runner do if the slope of the line is zero? What if the slope is negative? Add a second runner (a second graph) and connect real-world meaning to the intersection of two graphs.”

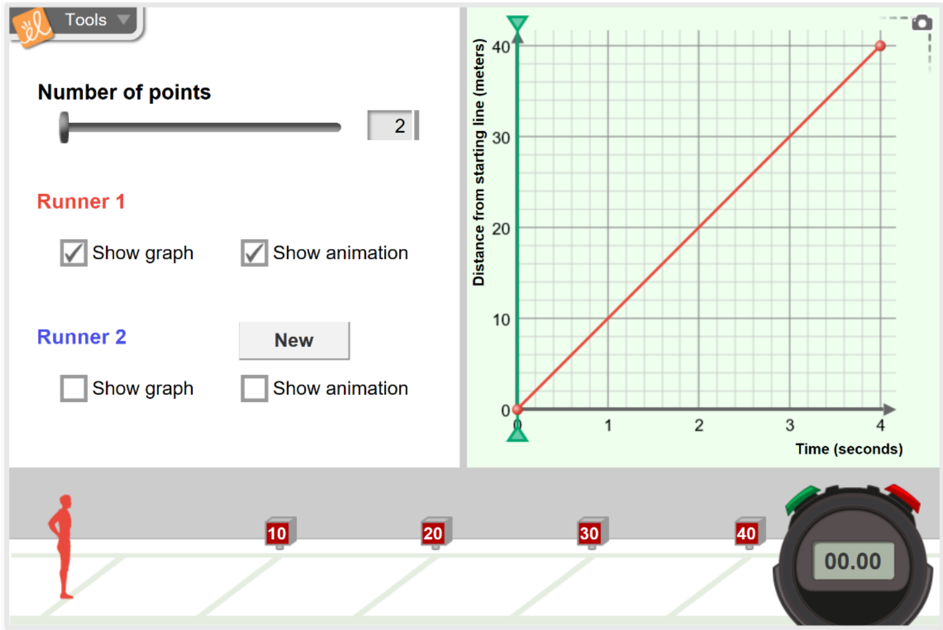


Image 4: Screenshot of the Distance-Time Graphs Gizmos activity. https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=625&ClassID=2647683

Roller Coaster Physics

This Gizmos Activity was completed as an individual activity after a teacher directed lesson on the science concepts being discussed. Those concepts included potential and kinetic energy as well as velocity. My main goal for this activity was for my students to have the opportunity to manipulate different variables in a real-life scenario. The objective on the Gizmos activity was to build a roller coaster that achieved “fun-experience” points, as well as making it to the end of the track and rolling to a gradual stop, versus crashing the roller coaster and injuring the people on board. You received points at the end for having a fun roller coaster and reaching your goal. I also put an interesting spin on this activity; I turned it into a competition for my students. I had all my students write their scores on the board and we kept track of who was on the leaderboard. At the end of the class period, whoever was in the top 3 received bonus points on their next exam.

Description from Gizmos: “Adjust the hills on a toy-car roller coaster and watch what happens as the car careens toward an egg (that can be broken) at the end of the track. The heights of three hills can be manipulated, along with the mass of the car and the friction of the track. A graph of various variables of motion can be viewed as the car travels, including position, speed, acceleration, potential energy, kinetic energy, and total energy.”

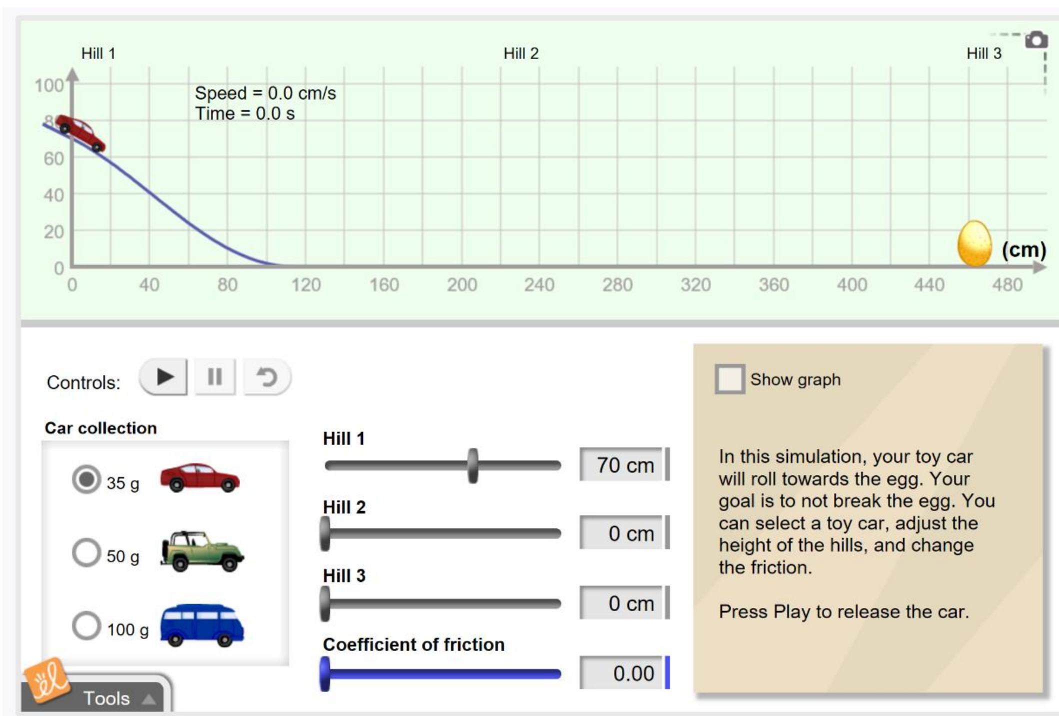


Image 5: Screenshot of the Roller Coaster Physics Gizmos activity. https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=405&ClassID=2647683

Waves

This Gizmos Activity was completed as a test review, in order to prepare my students for the upcoming assessment over the information. There was a packet to be completed as the students worked through the activity.

Description from Gizmos: "Observe and measure transverse, longitudinal, and combined waves on a model of a spring moved by a hand. Adjust the amplitude and frequency of the hand, and the tension and density of the spring. The speed and power of the waves is reported, and the wavelength and amplitude can be measured."

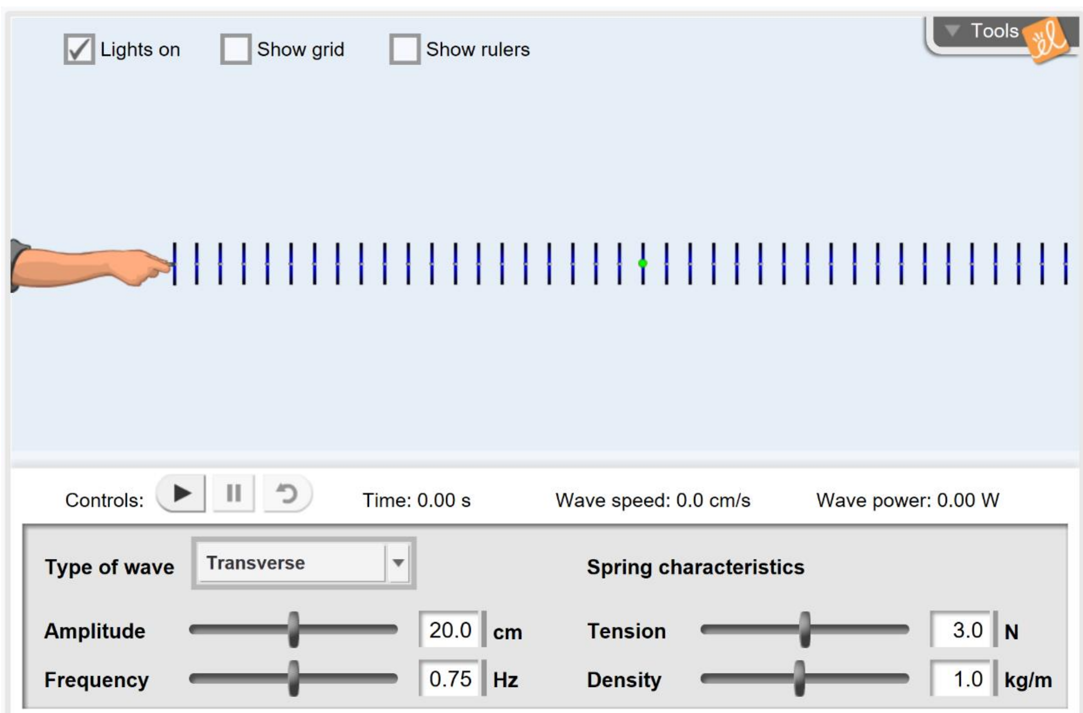


Image 6: Screenshot of the Waves Gizmos activity.

https://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=1053&ClassID=2647683

Impact on Student Interest and Engagement by Using Virtual Labs

As previously stated, student engagement within a lesson is important because when a student is engaged in a lesson, then they are more likely to have a better understanding of the science concepts being discussed. With that being said, one of my main objectives was to ensure that my students remained interested and engaged in the lesson that I was teaching. One way I did this was with the use of virtual labs.

Throughout my student teaching experience, I used simulations and Gizmos activities in a variety of ways. A benefit of having direct access to student voice, was that I was able to receive their direct opinion on this topic; whereas scientific articles analyze the facts and evidence surrounding their topic, and do not necessarily mention the opinions of people involved. One of the items that I was interested in was my students' interest in these activities and their opinions. Their interest and engagement are crucial because research suggests that students who are engaged in their learning, will retain more information than those students who are not interested in the science concepts being taught. In this section I will analyze results from a survey that I gave my students in order to analyze their interest and engagement.

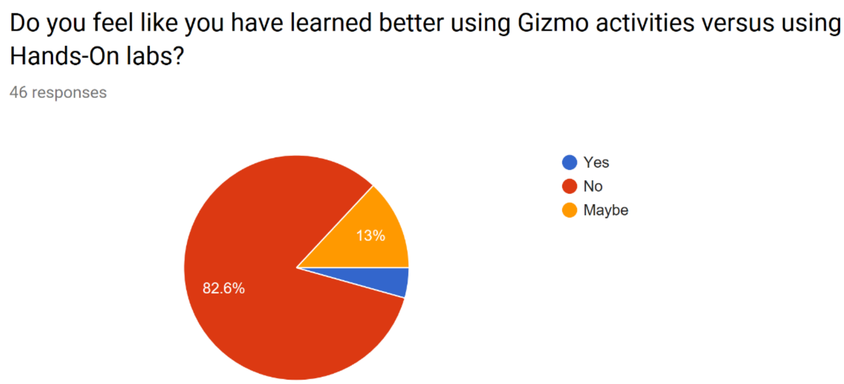
An important thing to note prior to viewing the survey results, is the fact that I was teaching within a freshmen physical science class, and unfortunately, Gizmos activities were slightly overused in their eighth-grade science classroom. Therefore, when it came time for me to utilize the Gizmos in my classroom, the students' automatic response was one of "annoyance" per say, so I had to overcome that initial barrier before they saw the benefit of the activity. The survey was given as a Google Form, where the students could log into their school email and pull-up the link to the survey. The questions that were asked can be found at the end of this paper in Appendix A. Table 2 summarizes the results.

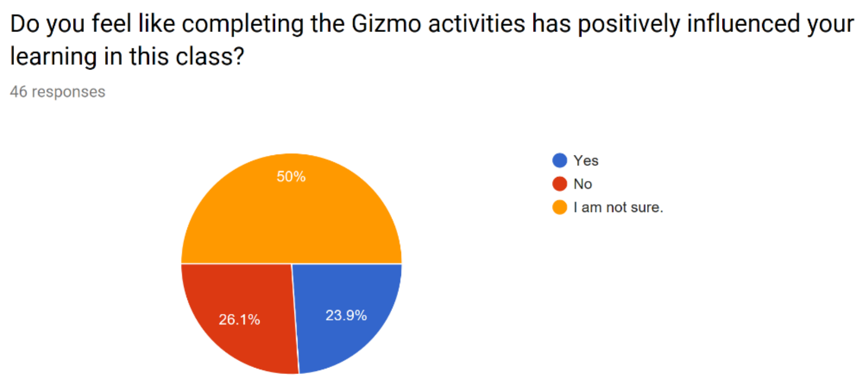
Why do you hate or love Gizmos? **(follow up question after a question where they were asked to rank Gizmos from 1 to 5 with 1 being "I hate them" and 5 being "I love them")**
They help my understanding of what we are learning.
They can take a while. But I feel like I learn more with them.
I kind of like them because they are easier to understand.
They helped me with understanding what we are doing in the chapter.
I like them because them show me visuals of the things we were learning.
They explain the topic in younger person terms and help to better understand the topic.
Gizmos provide an interactive lab experience that is good when a hands-on lab is not available, but not as good as hands on labs.
You are able to see the intended results without malfunction instead in a lab hoping it turns out well.
I'm in the middle because it's better than doing work sheet but takes too long.
They are helpful but, they take a lot of time to complete.
They aren't the most exciting thing, but I feel that they are effective for understanding certain concepts.
I'm in the middle because they can be better than normal class work, but they can also be annoying to do.
They worked to show as an example of things that are too big to be done in a classroom, however they don't provide much more learning than we already do. It seems as just "busy work"
They are a nice learning experience, but I would rather be taught by a human being.
I do not like them because they never really helped me understand the chapter we were learning any better for tests or quizzes.
I don't like them because they are tedious and annoying, and I would much rather spend my time doing a hands-on type of demo.
They take too long and aren't as helpful.
They're time consuming and don't teach me much.
Some of the questions are difficult to understand.

Table 2: Answers to one of the questions on the survey that was given to the students. The responses are organized into three main categories: positive, neutral & negative.

After viewing the student responses, it verified the assumptions I had made about my students' opinions towards Gizmos. I knew that many students saw their value, but they were not as interested in the information as I had hoped. As seen above, there were many negative responses including: "They take too long and aren't as helpful." However, there were many positive responses including: "Gizmos provide an interactive lab experience that is good when a hands-on lab is not available, but not as good as hands on labs." I was happy to see this response, because it showed that my students saw the value in the Gizmos activities. Overall, the responses to this question have left me feeling optimistic and have inspired me to change how Gizmos activities are used in the future.

Another important topic that I wanted to address was their opinion of hands-on labs compared to the virtual labs. Below are some of the questions that were asked and the results that I received following their responses.





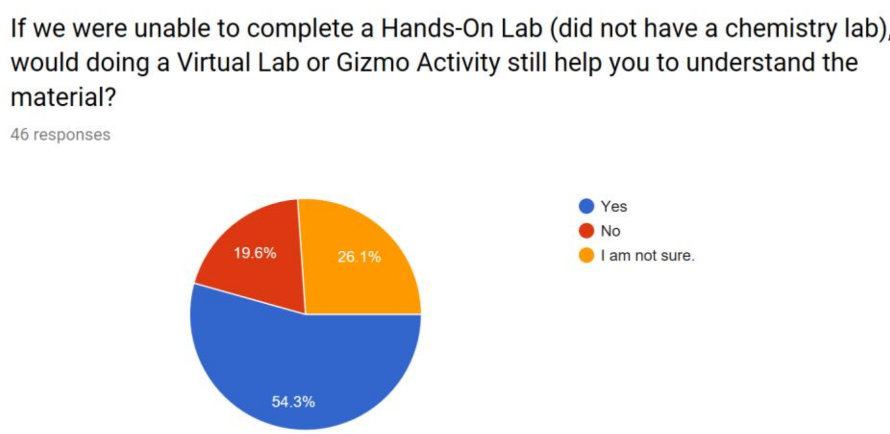


Figure 3: Students' responses to survey questions about their perceptions of using virtual labs in the science classroom.

As seen above, the students prefer hands-on labs compared to the virtual lab activities. Roughly 80% of the students felt that they did not learn better from the virtual labs compared to the hands-on labs. The next question asked if they felt like the virtual labs positively influence their learning within the classroom. Half of the students felt like they were not sure (which is a valid response for this question), but again, more students had a negative view of the virtual labs in comparison. The final question above is one that addresses what many researchers often ask: can virtual labs be utilized when you are unable to complete a hands-on lab? I asked my students this question for them to realize that in some places, students are not given nearly as many opportunities as they have here. With that in mind, over 50% of my students felt that the virtual lab would still help them understand the science concepts, if that was the only option they were given. Despite their positive response, I was unable to completely test this within my student teaching experience, because I did not want to take away the opportunity that my students had been given. They are accustomed to having the ability to complete hands-on labs and I knew they would feel more comfortable continuing to do so. However, due to their response, I know that I have the option of incorporating more virtual labs into my lessons in the future, as long as I place a higher importance on the completion of the activity.

Impact on Student Learning by Using Virtual Labs

Through many research studies, it has been found that virtual labs have a positive impact on student learning. According to Wieman, et. al. “We find that students are not able to make sense of the science in the simulation just from watching. They must interact actively with the simulation. Most of the learning occurs when the student is asking herself questions that guide her exploration of the simulation and her discovery of the answers. When students engage in such self-driven exploration, they learn better. For example, nonscience students with no prior knowledge of physics are able to provide quite good explanations of an electromagnetic wave after less than an hour playing with the “Radio Waves” simulation. (Even physics majors have a hard time explaining electromagnetic waves after a year of physics.)” (p. 683).

With that being said, I can agree with the fact that students’ learning is positively impacted by virtual labs. I have seen firsthand that my students have a better understanding of the science concepts after they complete a virtual lab activity.

Challenges Surrounding the Use of Virtual Labs

There are a few challenges surrounding the use of virtual labs in the science classroom. Two of those challenges include the fact that some students may not have access to technology at home and the other challenge being that the school needs to have a set-up within the building for the technology.

The teacher or school need to plan for students who may not have the money to have a computer at home. Otherwise it can be seen as unfair; so, if anything, we should have some type of laptop checkout procedure in order to combat this issue (Ngoyi, 2013). This is definitely a challenge when it comes to using virtual labs, because many students may only have access to technology at school. As a teacher, this fact needs to be taken into consideration when planning a lesson that uses technology. There needs to be adequate time in class for the students to use the technology. If a student needs more time, but does not have access to technology at home, then you need to devise a plan for them to finish the activity at the school.

One of the biggest considerations when planning to use technology is access to hardware and software that allow activities to be conducted smoothly (Ngoyi, 2013). The school needs to have the capability of housing that technology, as well as everything that comes along with it.

Even though these are two challenges surrounding the use of virtual labs within the classroom, the multitude of positive outcomes far outweigh those challenges. There are many different assortments of schools and how they teach the standard curriculum depending on their abilities through funding and resources. If a school is lacking science labs where students complete hands-on activities, but they have access to technology, then they are likely to have overcome these challenges listed above. Overall, if a school has the betterment of their students as their main goal, then they will be able to overcome any challenges that they may face.

Conclusions

In conclusion, it can be stated that: "Sims can be highly effective learning tools; however, even the best sims are not automatically successful. They are tools that can enhance a well-designed curriculum and the efforts of a good teacher, but they cannot replace them. They must still be part of an overall instructional design and rely on the timely guidance of a teacher." (Wieman et.al., 2010, p. 225). Overall, the main goal of this paper was to analyze the use of virtual experiments and simulations. I examined the learning theories in education and how virtual experiments are used in the science classroom. I also examined student interest with virtual experiments and how it impacts their learning. Lastly, I discussed some of the challenges that come along with the use of virtual experiments and simulations. Ultimately, my hope is that this information will be useful when incorporating virtual labs into your classroom.

Appendix A – Survey Questions

Virtual Labs vs. Hands-On Labs

Testing the effectiveness of online labs and simulations in the science classroom where there may not be time or resources to have hands-on labs.

What is your opinion on Gizmo activities? *

	1	2	3	4	5	
I hate them.	○	○	○	○	○	I love them.

Why do you hate them or love them? *

Long answer text

Do you feel like you have learned useful information by completing the Gizmo activities? *

	1	2	3	4	5	
No, I learned nothing.	○	○	○	○	○	Yes, I learned a lot of information.

Do you feel like you have learned better using Gizmo activities versus using Hands-On labs? *

- ○ Yes
- ○ No
- ○ Maybe

Would you rather complete a Hands-On Lab (ex: Hellercopter Lab) or complete a Gizmo Activity (ex: Roller Coaster Gizmo)? *

	1	2	3	4	5	
Hands-On Lab	○	○	○	○	○	Gizmo Activity

Do you feel like completing the Gizmo activities has positively influenced your learning in this class? *

- ○ Yes
- ○ No
- ○ I am not sure.

Do you feel that Gizmos prepare you for online state testing scenarios? (using a computer to take a test versus using paper and pencil) *

	1	2	3	4	5	
No, I did not feel prepared for online testing.	○	○	○	○	○	Yes, I felt very prepared for online testing.

If we were unable to complete a Hands-On Lab (did not have a chemistry lab), would doing a Virtual Lab or Gizmo Activity still help you to understand the material? *

- ○ Yes
- ○ No
- ○ I am not sure.

Have you used other online resources in other classes besides Science? If yes, please explain what resource you used (ex: Gizmo) and what the lesson was (ex: Waves). *

Long answer text

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